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Infrared surface pasteurization of Turkey frankfurters[☆]

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Abstract

A new intervention method has been developed using infrared heating to pasteurize the surface of turkey frankfurters contaminated with potentially fatal *Listeria monocytogenes* prior to final packaging. A laboratory infrared heating device was constructed to treat turkey frankfurters coated with approximately ten 6–7 cells/cm² of a four-strain mixture of freshly prepared *L. monocytogenes*. The surface temperature of frankfurters was increased from refrigerated conditions to a final temperature of 70, 75 and 80 °C, achieving an average of 3.5 ± 0.4, 4.3 ± 0.4 and 4.5 ± 0.2 (mean ± S.E.) log-reductions in bacterial counts. No noticeable physical damage to the heat-treated samples was observed. Although the heat-treated samples were slightly browner than the control by visual observation, the measured color attributes (L*, a* and b*) were not significantly different from the control after a few hours of refrigerated storage. Experimental results of this study suggested that infrared surface pasteurization potentially could be used as an intervention technology to kill *L. monocytogenes* contaminated on the surface of frankfurters immediately prior to final packaging and reduce the risk of foodborne listeriosis caused by these products.

Keywords: Infrared heating; Frankfurters; Surface pasteurization; Cooked meat; *Listeria monocytogenes*

Industrial relevance: This paper attempts to apply infrared energy for surface pasteurisation of solid food surfaces especially ready-to-eat meat products immediately prior to packaging. The data suggest that infrared pasteurisation can become a promising technology for surface pasteurisation of solid foods and for the prevention of recontamination during subsequent processing.

1. Introduction

Listeria monocytogenes is a serious foodborne pathogen that has been associated with many outbreaks in recent years in the United States (CDC, 1998, 2000, 2002). This organism is a Gram-positive, rod-shaped, facultative bacterium. It is distributed in a variety of environments, including soils, water, sewage and animals. Human foodborne listeriosis, although rare, has caused a high rate of mortality (>20%) among high-risk populations. Immunosuppressed individuals, such as the elderly, pregnant women, fetuses and neonates, are particularly susceptible to *L. monocytogenes*. This organism has been isolated from a variety of foods, including raw and processed meat and poultry products, seafood, salads and unpasteurized dairy products. Ready-to-eat meat/

poultry products, such as frankfurters and deli meats, are frequently contaminated with *L. monocytogenes* (CDC, 1998, 2000).

Although *L. monocytogenes* is generally more heat resistant than many non-spore-forming microorganisms (Mackey & Brachell, 1989), this organism can be completely inactivated with sufficient cooking time under appropriate heating temperatures during meat processing (Beuchat & Brackett, 1989; Mackey, Pritchett, Norris, & Mead, 1990). Therefore, ready-to-eat meat products are supposedly free of *L. monocytogenes* after thermal processing. However, post-processing recontamination often occurs in processing facilities. According to a joint study conducted by scientists from CDC and USDA in a turkey franks manufacturing facility, contamination of *L. monocytogenes* primarily occurred in the peeling process of fully cooked turkey franks immediately prior to the packaging of products (Wenger et al., 1990). Under improper refrigerating and handling conditions, this organism can grow/multiply in packaged products. As a result, ready-to-eat meat products contaminated with *L. monocytogenes* may enter the market, potentially

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causing outbreaks of human listeriosis. While it is critical to prevent the potential recontamination after cooking, an intervention technology may be needed to inactivate *L. monocytogenes*. High temperature can be used to in-package pasteurize food products. However, this process would render the products another long cooking process that may deteriorate their quality. Since recontamination primarily occurs on the surface area, superficial heating may be used to destroy the contaminating organisms immediately before the products are packaged.

Infrared energy is an excellent heat source for many industrial applications. It has been widely used in the food industry to dry various kinds of grains and cereal products. It also has been used in penetrative heating of relatively thick foods, such as drying of potato (Afzal & Abe, 1998), cooking of meat patties/burgers (Sheridan & Shilton, 1999, 2002) and baking of biscuits (Wade, 1987). Its application in surface pasteurization has not been reported.

Infrared is a unique heat source. Its thermal energy is primarily absorbed on solid food surfaces and has very limited penetration capability. Exposing an object (such as a solid food) to an infrared heating source would cause its surface to increase in temperature. As the surface temperature increases, heat is consequently transferred to the center of the solid food by conduction. Since most solid foods are generally low in thermal conductivity, the rate of heat conduction to the interior is very slow when compared with highly conductive materials (such as metals). If a high-temperature infrared source is used to radiate meat products such as frankfurters, the intense heat may accumulate on the surface area, causing its temperature to increase rapidly. If

the infrared exposure time is properly controlled, the surface temperature of meat products can be preferentially raised to a degree lethal to *L. monocytogenes* without causing the interior to substantially increase in temperature. If the products are immediately packaged, potentially they may be free of *L. monocytogenes*. Therefore, the objective of this study was to test the feasibility of using infrared to surface-pasteurize ready-to-eat meat products (such as frankfurters) immediately prior to final packaging.

2. Material and methods

2.1. Infrared heating apparatus

An infrared heating apparatus was designed for surface pasteurization using two ceramic emitters (60×245 mm) obtained from Mor Electric Heating Assoc. (Comstock Park, MI). The emitters were rated at 1000 W and operated at 240 Vac with a nominal infrared emission efficiency of 96%. Although the maximum operating temperature of the emitters was 700 °C, the operational maximum temperature in the laboratory was approximately 545–550 °C.

The two infrared emitters were arranged vertically in parallel with the two emitting surfaces facing each other (Fig. 1). The distance between two emitters was 14 cm (or 5.5 in.). Two aluminum reflectors were installed behind the emitters to redirect the infrared waves and enhance the efficiency of infrared radiation. Two Type J thermocouples were inserted to the emitters and connected to a fuzzy logic PID controller (Model CN4431, Omega Engineering, Stam-

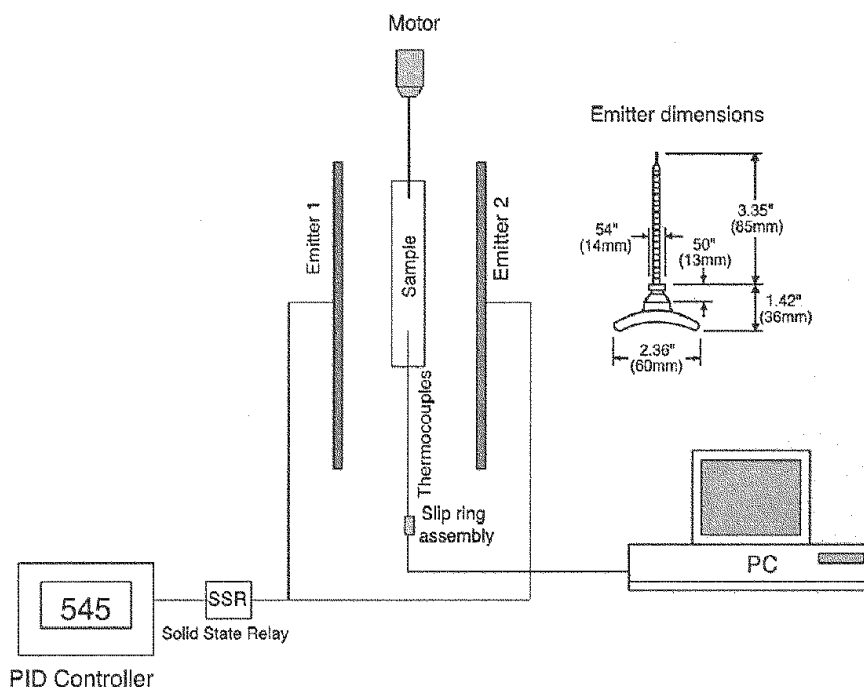


Fig. 1. Infrared heating device used in this study.

ford, CT). The emitter temperature was controlled through a solid-state relay (SSR, Model SSR240AC25, Omega Engineering). In all the experiments, the temperature of the infrared emitters was controlled at 545 ± 1 °C by the PID process controller.

Vertically above the infrared heaters, an electric motor was installed with a specially designed metal hook to hang the frankfurter samples between the infrared heaters. The frankfurter sample rotated along its axial direction as the electric motor turned. This setup was used to emulate the rotation of frankfurters on a conveyor belt. The speed of the electric motor was controlled through a transformer. The frankfurter samples rotated with the motor at a speed of 80 ± 2 rpm. The motor speed was monitored during the surface-heating experiments by manually counting the total revolutions of the frankfurter samples within a fixed time period (15 s).

2.2. Temperature measurement

To measure the surface temperature, a thermocouple (Type J, Gauge 30, Omega Engineering) was attached to each frankfurter using high temperature plastic cable ties. The tip of each thermocouple was located approximately 4–5 cm from one end of a frankfurter and was tightly in contact with the sample surface. A small portion of the thermocouple tip was partially buried beneath the surface. The thermocouple was connected to a data acquisition board (Model NI4351, National Instruments, Austin, TX). The frankfurter surface temperature was continuously monitored and recorded at a 1 s interval using a data acquisition tool (LabView, Version 6.0, National Instruments).

There was a possibility that the thermocouple might be directly heated by the infrared waves due to thermal radiation. However, since the tip was so small (0.25 mm in diameter for each wire with a response time < 0.3 s) and it was tightly attached to the sample, the heat absorbed by it was either negligible or quickly conducted to the frankfurter surface. Throughout the process of surface pasteurization, the point on the frankfurter surface in contact with the thermocouple tip was thermally in equilibrium with the surrounding area that was directly exposed to infrared radiation. Therefore, it was assumed that the measurement error was negligible and the thermocouple was measuring the true temperature of the surface of the frankfurter sample.

2.3. Bacterial strains

Four strains of *L. monocytogenes* (7644, 43256, 15313 and 49594) obtained from Dr. Christopher Sommers of USDA-ARS-ERRC were used in this study (Sommers & Thayer, 2000). These strains were originally obtained from the American Type Culture Collection (Manassas, VA). Their identities were confirmed by Gram Positive Identification cards using Vitek Automatic System (bio-

Merieux Vitek, Hazelwood, MO). The bacterial strains were initially propagated in Tryptic Soy Agar (Difco Laboratories, Detroit, MI) at 37 °C and remained refrigerated (~ 10 °C).

2.4. Bacterial cultures

Each strain was grown in 100 ml of Brain Heart Infusion broth (BHI broth, Difco Laboratories) in a 250-ml Erlenmeyer flask at 37 °C for 24 h in an orbital shaker (Labline Environmental Shaker, Model 4628, Barnstead/Thermolyne, Dubuque, IA) operated at 135 rpm. The bacterial cells were then harvested in a refrigerated centrifuge (Model Marathon 21000R, Fisher Scientific, Pittsburgh, PA) operated at $2400 \times g$ for 30 min at 4 °C. After washing once with 50 ml of sterile de-ionized water, pellets of each strain were combined and re-suspended in 200 ml of sterile 0.1% peptone–water. The bacterial suspension was poured into a sterile stainless steel pan and kept in a refrigerator (~ 10 °C) until ready for use (< 30 min).

2.5. Preparation of samples

Commercially available turkey frankfurters were purchased from a local grocery store. This generic brand product was available in most grocery stores. Each frankfurter was approximately 2 cm in diameter and 15.5 cm in length. Prior to inoculation, a thermocouple was attached to the frankfurter surface using the method described previously.

Each frankfurter with the thermocouple was quickly dipped into the *L. monocytogenes* suspension prepared previously until the whole sample was fully immersed and then immediately removed from the pan following the full immersion. After inoculation, the frankfurters were placed in a plastic pan and kept in a refrigerator until ready for use (< 30 min).

2.6. Infrared surface pasteurization

The sample was removed from the refrigerator, attached to the metal hook and then quickly connected to the motor. After the frankfurter sample was fixed to the electric motor, the motor was actuated. As the frankfurter sample rotated axially, the surface temperature rose gradually. The rotation of the frankfurter sample continued until the surface temperature was raised to 70, 75 or 80 °C (end point temperature). The frankfurter sample was quickly removed from the heating device. A middle section (4–6 cm) was aseptically dissected from the infrared treated sample and then immediately transferred to a 250-ml Erlenmeyer flask containing 100 ml of ice-cold sterile 0.1% peptone–water to allow rapid cooling. Each Erlenmeyer flask containing the infrared treated frankfurter sample was then maintained on ice (< 1 h). For practical purpose, the sections covered by the thermocouple and metal hook were discarded. Only the

sections directly exposed to infrared waves were used for determination of bacterial counts. Three frankfurter samples were used for each temperature treatment in an experiment. The experiments for each temperature treatment were replicated five times.

2.7. Determination of bacterial counts

The control and heated samples (mid sections, 4–6 cm) were washed in the Erlenmeyer flasks containing 100 ml of refrigerated 0.1% peptone–water. The washing was conducted in an orbital shaker (Labline Environmental Shaker, Model 4628, Barnstead/Thermolyne) operated at a rotational speed of 135 rpm for 10 min. Using the orbital shaker to wash the samples allowed more uniform mechanical agitation for all samples.

The wash solution was serially diluted and surface-plated onto freshly prepared PALCAM *Listeria* selective agar (van Netten, Perales, van DE Moosdijk, Curtis, & Mossel, 1989). Three plates were prepared per sample per dilution. The plates were placed at room temperature for 2 h prior to incubating at 37 °C for 48 h. The plate counts were converted to the logarithms of bacterial counts/cm² of the frankfurter surface.

2.8. Effect of infrared surface heating on color

To evaluate the effect of infrared surface pasteurization on the color of frankfurters, a spectrophotometer (BYK-Gardner Spectrophotometer, Model 8800, BYK-Gardner, Silver Spring, MD) was used to measure the color attributes of infrared treated samples. This spectrophotometer was operated through The Color Sphere TM Color System under a PC-DOS operating system.

A complete series of infrared surface heating was conducted using samples not previously inoculated with *L. monocytogenes*. After heating, the infrared treated samples were placed in plastic bags. Each plastic bag was vacuum-sealed to a final vacuum level of 45 mm Hg and then refrigerated on ice. Determination of color attributes was conducted after 1, 2 and 20 h of refrigerated storage.

The color attributes were measured with the plastic bags for heat-treated and control samples to prevent contaminating of the spectrophotometer. The measurement was conducted by the measuring the reflectance of the samples using a small area reflectance port and a 2° view angle. The sample color attributes were represented using the CIELAB color space system and quantified by the values of L*, a* and b* (Claus, Shaw, & Marcy, 1994).

2.9. Statistical analysis

A statistical procedure (GLM) of SAS Version 8 (SAS, 1999) was used to compare the effectiveness (mean log reduction) of infrared surface pasteurization and the mean values of L*, a* and b* of the samples.

3. Results and discussion

3.1. Characteristics of infrared waves

At a constant temperature, a spectrum of infrared waves can be generated from the infrared source. The maximum wavelength (λ_m) emitted from infrared heaters can be calculated from the absolute temperature of the emitting source (Eq. (1)), according to Wien's displacement law (Knudsen et al., 1984). At 545 °C or 818 K, the theoretical maximum wavelength emitted from the infrared source was 3.54 μ m. This wavelength was located in the medium-to-far infrared wave range where thermal effects were significant (Dagerskog, 1979; Dagerskog & Osterstrom, 1979).

$$\lambda_m = \frac{2.898 \times 10^{-3}}{T_K} \quad (1)$$

According to Bolshakov et al. (1976), the penetration depths of infrared radiation into cooked meats were 2.3, 1.0 and 0.7 mm at λ_m values of 1.07, 2.4 and 4.2 μ m, respectively. Since the wavelength used in this study was 3.54 μ m, the infrared penetration depth may be between 0.7 and 1.0 mm. Because a frankfurter was a solid material, conduction was the primary method for internal heat transfer. Its rate was affected by the thermal diffusivity of frankfurters. For meat/poultry products, however, the thermal diffusivity is usually very low, ranging between 1.0×10^{-7} – 2.0×10^{-7} m²/s (Rahman, 1995). With such a low thermal diffusivity, the conduction of heat from the surface to the interior in meat/poultry products can be a slow process. Therefore, the infrared heating would primarily concentrate on the surface of frankfurters, resulting in a preferential heating on the surface. If not properly controlled, the product surface can be severely burnt, while the interior of frankfurters is not directly affected by the infrared energy.

3.2. Surface temperatures

The surface temperature increased immediately in response to the infrared waves when the frankfurter samples were exposed to infrared radiation and began to decrease gradually after the samples were removed from the infrared sources (Fig. 2). For all the inoculated samples, the initial surface temperature should be approximately 10 °C since the samples were previously maintained in a refrigerator. However, the surface temperature gradually rose above 10 °C during sample preparation prior to infrared heating since the room temperature (~20 °C) was higher than the sample temperature. Although there was some variation in the initial surface temperatures, the average time for the surface to reach the end heating temperatures of 70, 75 and 80 °C was 82.1, 92.1 and 103.2 s, respectively. For all the tests conducted, the center temperatures remained below 20 °C.

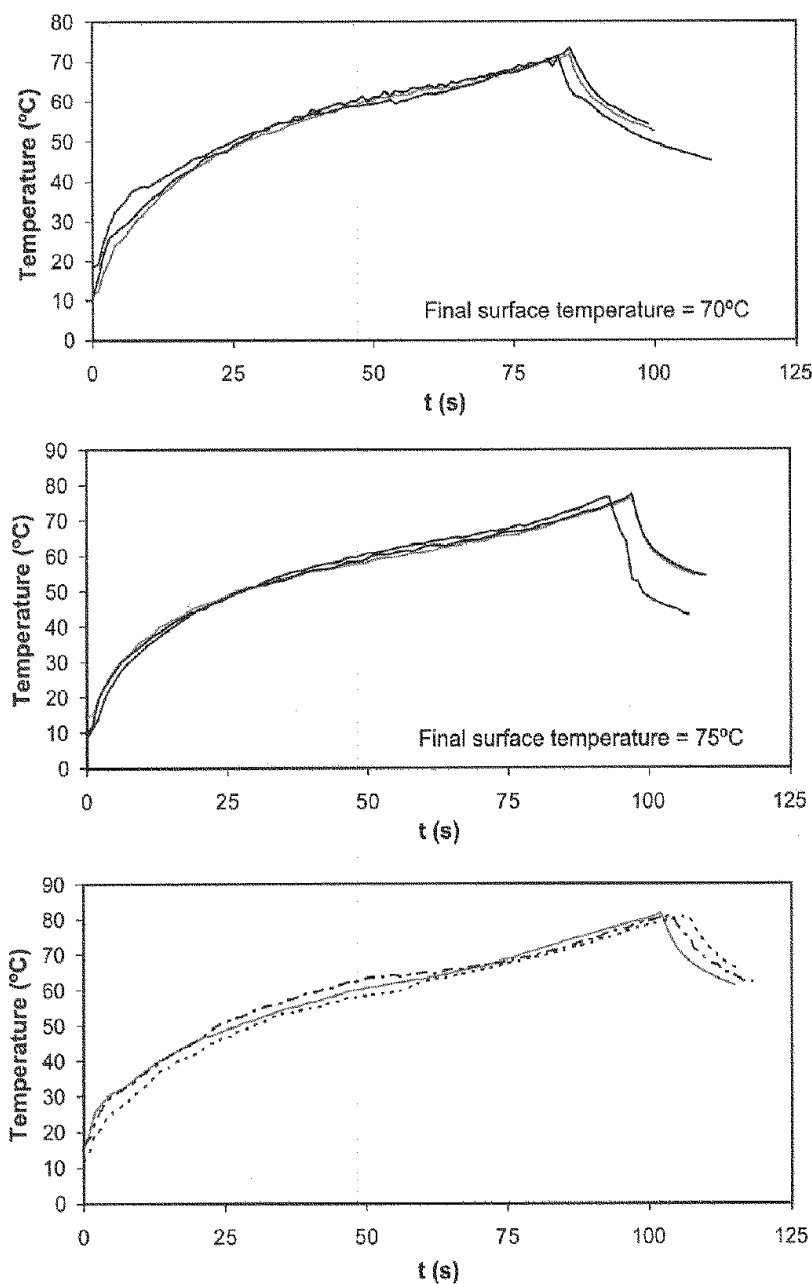


Fig. 2. Experimental surface temperature curves during infrared surface pasteurization.

3.3. Inactivation of bacteria

The average bacterial concentration of *L. monocytogenes* inoculated onto the surfaces of frankfurters was 6.4 log(CFU/cm²) with a very small standard error (0.2), indicating the samples were fairly homogeneously inoculated. This inoculation level was very high in cooked meat/poultry since no *L. monocytogenes* is permitted in real products. Even in raw meat products, the concentration of this organism is very low, and usually below 3 logs (Zaika et al., 1990). *L. monocytogenes* detected at the level of 6.4 logs in ready-to-eat products would indicate that the hygienic condition in the manufacturing facility be extremely poor.

Since the samples were overloaded with bacteria, the original samples were not tested for the existence of *L. monocytogenes*.

Fig. 3 shows the effect of the infrared heating on bacterial inactivation. After the surface temperature was raised above 70 °C, different degrees of bacterial killing were observed. It was difficult to maintain frankfurter samples absolutely aligning with the central axis between the heaters during the experiments. Therefore the samples might be "wobbling" along the central axis. This may have caused some variation in the surface temperature development among the samples, leading to some difference in the bacterial kill. On average, *L. monocytogenes* on turkey

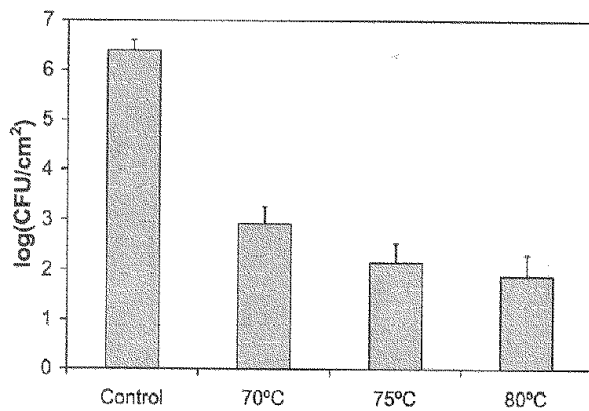


Fig. 3. Effect of infrared pasteurization on survival (mean and S.E.) of *L. monocytogenes* coated to the surfaces of turkey frankfurters.

frankfurters was reduced by 3.5 ± 0.4 , 4.3 ± 0.4 and 4.5 ± 0.2 logs (mean \pm standard error), respectively, after the surface temperature was raised to 70, 75 and 80 °C. However, the difference observed in the mean log reduction at all these three temperatures was not statistically significant ($n=5$, $p>0.108$).

Immediately following the infrared treatment, the surface of frankfurter samples was visually browner in color than the control. However, the surface color of infrared heated frankfurters gradually returned to normal after 1 h of refrigerated storage. Although the surface-heated samples after refrigerated storage were slightly darker by visual observation, the color attributes also were not significantly different from the control ($p>0.11$).

This study was conducted using cells of *L. monocytogenes* directly inoculated onto the surface of frankfurters. The effectiveness of infrared surface pasteurization is comparable to other surface pasteurization methods reported in the literature (Cygnarowicz-Provost, Craig, & Whiting, 1995; Cygnarowicz-Provost, Whiting, & Craig, 1994; Kozempel, Goldberg, Radewonuk, Scullen, & Craig, 2000). In both studies conducted by Cygnarowicz-Provost et al. (1994, 1995), saturated steam was used to kill *L. innocua* inoculated onto the surface of beef frankfurters. A 4-log reduction was reported with treatment times of 30–40 s at 115–136 °C. The vacuum–steam–vacuum (VSV) processes developed by Kozempel et al. (2000) achieved 3–5 log reductions in the bacterial counts of *L. innocua* inoculated onto the surface of beef frankfurters. In all these VSV pasteurization processes, *L. innocua* was used instead of the more heat resistant *L. monocytogenes*. The effectiveness of the VSV pasteurization processes for killing *L. monocytogenes* has not been tested directly. This study showed that the infrared pasteurization could achieve at least 3.5 logs reduction in *L. monocytogenes* coated onto the surfaces of turkey frankfurters. This process is sufficient to kill the low level contamination of *L. monocytogenes* on the surfaces of frankfurters in processing plants.

The infrared surface pasteurization may be easier to implement in the food industry since infrared heating is a

mature industrial technology and has been widely used in many industrial applications. To use infrared surface pasteurization in the industry, the conveyor must be modified to allow the rotation of frankfurters. A bank of infrared heaters can be installed on top of a conveyor to heat the surface of frankfurters. The infrared treated products can be directly fed to a packaging machine. Since the heat accumulated on the product surface does not dissipate immediately, the residual heat will help prevent further contamination when the products are being fed to the packaging machine. In combination with other intervention technologies, the infrared surface pasteurization may be optimized and become a valuable tool to reduce the risk of foodborne listeriosis caused by ready-to-eat meat/poultry products.

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